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*K. W. Franklin, L. N. Howell, Jr., D. G. Lewis, C. A.
Neugebauer, D. W. O'Brien, S. A. Schilling*

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Kenneth W. Franklin, BWXT-Pantex
L. Neville Howell, Jr., BWXT-Y12
Danny G. Lewis, Honeywell-KCP
Carolyn A. Neugebauer, SNL
Dennis W. O'Brien, LLNL
Scott A. Schilling, LANL

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Executive Summary

The purpose of this White Paper is to outline the benefits we expect to receive from Model-Based Engineering and Manufacturing (MBE/M) for the design, analysis, fabrication, and assembly of nuclear weapons for upcoming Life Extension Programs (LEPs). Industry experiences with model-based approaches and the NNSA/DP investments and experiences, discussed in this paper, indicate that model-based methods can achieve reliable refurbished weapons for the stockpile with less cost and time. In this the paper, we list both general and specific benefits of MBE/M for the upcoming LEPs and the metrics for determining the success of model-based approaches. We also present some outstanding issues and challenges to deploying and achieving long-term benefit from the MBE/M.

In conclusion, we argue that successful completion of the upcoming LEPs—with very aggressive schedule and funding restrictions—will depend on electronic model-based methods. We ask for a strong commitment from LEP managers throughout the Nuclear Weapons Complex to support deployment and use of MBE/M systems to meet their program needs.

Background: Preview of MBE/M Benefits from Industry and NWC

Model-Based Engineering and Manufacturing (MBE/M) starts with 3D solid models of mechanical parts and assemblies, and electronic, electrical and electro-mechanical models designed on computer-aided design (CAD) workstations. Models are enriched with specifications, notes, materials, usages, geometric tolerances, surface finishes, characteristics, revision levels and related descriptive information needed for physics and engineering analysis, and for manufacturing. These solid models serve as the basis for mesh generation for physics calculations and engineering structural and thermal analysis by the design agency. Once the design agency is satisfied that their models represents the design-intent and they are verified and validated through physics and engineering analysis and testing, the models are ready for release and authorized for manufacture by the production agencies.

It is a goal of MBE/M to effectively use 3D solid models from the design agency as *product definition* for the production agency, fully representing the design-intent. These models are to be used in production planning, the design of fixtures and tooling, clamp points for machining and assembly, machine tool path generation, and part and assembly inspection. Having this level of weapon design detail in an electronic format also allows business systems and process models to be used to optimize engineering, integration, and scheduling across the Nuclear Weapons Complex (NWC). Today, much of the solid model development in the NWC is accomplished using Pro/Engineer™ CAD software—a \$6M+ investment in FY01 alone. For electronics and electrical design, Kansas City Plant and Sandia have a bilateral agreement to use Veribest™ CAD design product definition.

The automotive, aerospace, and other manufacturing industries have led the way, moving to MBE/M methods to achieve *better, cheaper and faster* products to market. For example, the automobile industry has reduced the development time for new automobiles from 60 months to 30 months. By doing so, they gain market share and increase profits.

NWC sites have already been working to introduce model-based methods—both internally and between sites—with some notable successes, which we discuss below. We are using solid models to produce analytical meshes used in physics and engineering analysis at the Laboratories. We are using model-based approaches to design and fabricate special tooling for assembly and disassembly, evaluation, and inspection of weapon components and assemblies at the Plants. By starting with the weapon design model, the time for the tooling design and prototype fabrication to tool deployment for weapons operations has been reduced, and a direct link to the official product (component or assembly) definition maintained.

However, this is a departure from past NWC practices that relied on 2D drawings as weapon component and assembly product definition between the Laboratories and the Plants. Today, weapon *Record Of Assemblies* are 2D drawings, and the *Image Management System (IMS)* weapon design archive supports only 2D drawing images.

During the 1990's, NWC working groups were established to help deploy model-based tools. These groups strongly influenced the choice of tools currently deployed and have enabled easy transfer of information between sites. These groups also share the implementation issues and can leverage each other's work to solve problems for the Complex.

In October 2000, we were directed by National Nuclear Security Agency/ Office of Defense Programs (NNSA/DP) to apply model-based methods across the Complex for B61 LEP design and production, and follow-on W80 and W76 LEPs.¹ We have accepted the challenge with some certainty of a better process and product for the effort. Now the test is how best to implement model-based methods; what investment is yet needed; which agency or site needs to implement what capability for which weapon LEP?² This is a lot to answer very quickly. And, of the questions *why*, *what benefits are to be gained*, and *when*—we have a pretty good idea of the answers.

The Problem And Reasons Why MBE/M Makes Sense

Business practices of the past are inadequate for the NWC sites to meet the redesign-to-refurbishment needs of planned LEPs. We just don't have the time, people or funding to continue with business as usual. What we do have in hand is a MBE/M approach, which offers demonstrated benefits to manufacturing quality, schedule and costs.

At the Plants, MBE/M would significantly reduce machining time. A NWC pilot study indicated that roughing machined parts was reduced from 17.5 to 8.7 hours on average, and part finishing from 32.0 to 19.7 hours with model-based methods. This represents an average 45% savings in time. Similar timesavings are predicted by automating design, documentation, inspection, and tool path programming.

The Kansas City Plant (KCP) used a real production problem to verify the use of MBE/M tools and their potential savings. In 1998, a problem was identified with the process used to connect a gas bottle assembly to its next assembly components. The visualization advantages of 3D model design definition enabled engineers to identify the problem more quickly. KCP performed two separate tolerance studies—the first involving two experienced designers to identify the problem and make calculations manually, and the second using 3D solid models. Using hand calculations, the first method took 600 staff-hours to identify the features that needed modification to correct the problem. The second method, using models and tolerance analysis software, took less than 100 staff-hours, producing the same results. KCP estimates that identifying and resolving this issue saved at least \$600K+ in scrap and rework costs during the first year of production.

¹Memorandum: *Models-Based Product Realization for Weapons Systems*, D. H. Crandall and D. E. Beck, October 13, 2000.

² *Models-Based Product Realization Roadmap*, NNSA Office of Defense Programs, April 13, 2001

Outyear savings could be realized through reduced staffing. For example, at Pantex Plant, two full time records clerks—at \$300K per year—repeatedly sort through hard copy legacy data records to recover information requested by the Design Laboratories. However, they can recover only about 10% of the information requested. We can electronically store and sort weapon design models and as-built component and assembly records. This electronically captured information doesn't have to be repeatedly reviewed and transcribed and would be available for real-time knowledge-based decision-making. This would also result in fewer design revisions and less engineering paperwork, and could easily save \$3-5M per year.

There are other outyear savings. For example, industry analysis indicates that engineers spend 60% of their time looking for information; at LANL, weapon engineers spend as much as 30% of their time researching weapon-specific design and production information. This estimate includes confirming the validity and pedigree of design-intent and *as-built* records from the Plants. Based on this assumption, 50 engineers working on a weapon LEP would cost \$4.5M per year simply researching needed design and production information. By automating this process with model-based methods savings might be in the neighborhood of \$20-35M in deferred costs for the three upcoming LEPs. Deferred costs at the Laboratories would be put back into testing and analysis to reduce design and certification risk, and return a better quality weapon to the stockpile.

If we don't use model-based approaches now, we will continue to incur these cost inefficiencies after weapon refurbishments. A model-based approach, on the other hand, incurs significant up front cost in capturing models as product definition for components and assemblies for which we do not have a validated model. However, we probably would need to go through much of the same process even if we stuck with 2D drawings. It's an incremental cost to take the validated model and translate it into a validated product definition.

Benefits of MBE/M

Benefits from the Complex-wide application of MBE/M are real but difficult to measure precisely in a return-on-investment business sense. However, we expect significant improvements in the quality of product returned to the stockpile. Form, fit, and function as manufactured and assembled by the Plants will more closely meet the Laboratories' design-intent. The second benefit will be a real reduction in time from design, analysis, test, and design-release to production planning and execution. The upcoming three LEPs are very demanding, and MBE/M is our best option for meeting the aggressive schedules. The third benefit, and probably the last to be realized, will be lower costs, especially deferring outyear costs. Specifically, the Plants will realize direct benefit from model-based methods, lowering production costs and product and process acceptance by the Laboratories and NNSA. Benefits to the Laboratories will be indirect through lower cost, quicker turn around, and higher quality products and assemblies for ground and flight-testing for weapon certification. Much of the reduced cost will

be realized well into a LEP production and through lifetime weapon surveillance and certification.

Specific benefits to be realized through Model-Based Engineering and Manufacturing include:

- Improved quality of design, physics and engineering analysis and testing by starting with validated stockpile models and maintaining the pedigree.
- Improved quality of engineering by formal computer-based processes and better, more complete documentation.
- Reduced engineering time by 20-30% by starting with validated stockpile models.
- Reduced or eliminate redundant, sometimes inconsistent, re entry of information by sharing common design definition files and descriptive *metadata* information.
- Reduced design and process changes through Laboratory-Plant collaboration on designs early in the design process.
- Achieve better planning and resource use in manufacturing, assembly, component and assembly test and acceptance.
- Reduced returns rework iterations due to inconsistent practices by developing and supporting standards.
- Reduced manufacturing cycle times; cycle time reductions of 50% and cost savings of 40% have been noted in the design and fabrication of special tooling.
- Reduced machining time with advanced machine tools able to generate tool paths from models.
- Improved content, trace ability and retrieve ability of the information through generation of *Interactive Electronic Procedures (IEPs)*.
- Achieve better quality, decreased time (compressed schedule) and reduced costs for LEP re-design through refurbishment.

Possible MBE/M Metrics for Success

In introducing any new process into manufacturing, it is wise to establish metrics to determine the degree of success or benefit from an investment. Some benefits or savings may be incidental or explained best as anecdotes or trends (e.g., new MBE/M tools help attract and keep new talent in the weapons programs). Those observations that can be measured and quantified are valuable when recorded and analyzed. The following metrics are quantifiable observations to determine the value of our MBE/M investments:

- Number of times a weapon part or assembly model has been redrawn.
- Number of accesses to each site's *Product Data Management (PDM)* system; activity in the amount of data shared across the NWC.
- Number of concurrent vs. collaborative design efforts.

- Cost and time to produce tooling and fixtures, numerically controlled (NC) part programs, and approved working procedures after the *Advance Engineering Release* is released.
- Number of times the design agency is contacted during manufacture for clarification.
- Number revisions to an Advance Engineering Release.
- Number of calls to the Image Management System clerks.
- Number of *Advance Change Orders* or *Future Change Orders*, and *Final Change Orders* after a *Certified Engineering Release*.
- Time laps between Certified Engineering Release and *Drawing Transfer Engineering Release*.
- Number of requests to locate legacy data.
- Number of *Special eXception Requests*.
- Number of prototypes built.
- Scrap rate of parts.

Outstanding Issues & Challenges

Implementing MBE/M practices across the NWC means solving technical problems; problems with suppliers of commercial CAD and Computer-Aided Manufacturing (CAM) systems; NWC infrastructure and secure computer communication problems; and organization problems at NWC sites. This is not new—we have been working toward this end for years. But deploying and verifying MBE/M procedures will require investment at NWC sites. Our MBE/M processes have to include the same functions as the design, release and manufacture of designs from 2D drawings, only in a different way:

- The Design Laboratories have to verify and validate models as product definition, just as 2D drawings have been in the past.
- Models have to be released by the Laboratories to the Plants for manufacturing through a formal *Engineering Authorization* process.
- Models have to be archived, much as we archive 2D drawings in the Image Management System today.
- *Weapon Record Of Assembly* has to be recorded.

In the past, policy, procedural and technical issues have made it difficult to use machine intelligent CAD models—rather than human intelligent drawings—as the official product definition (document-of-record). When models deviated from drawings—as they often did—an ambiguous product definition resulted. Today we are still validating the human intelligent drawing as the released product definition.

Successful implementation of MBE/M practices relies on the predictable interchange of solid models between CAD systems. It also relies on using the model as product definition in a way that allows it to be evaluated, validated, and authorized. Interchanging 3D solid models between different CAD systems can

result in problems, more so than moving 2D flat plot files between display devices. Solid models can acquire anomalies as a result of being transferred between different CAD and CAM systems and other product realization processes. There are now modern QA tools to identify and fix many of the common anomalies.

It should be noted that we are relying on commercial, vendor-supplied model design tools and validation tools. Standard commercial tools enable model-based methods but represent a risk as vendors change their products and as sites change preferred vendors and products. Designers, engineers and managers will need to engage in a vigorous and continuous standards effort.

Each site's use of Pro/Engineer™ for mechanical design enables the successful use of solid models as product definition. As new versions of Pro/Engineer™ are released, NWC sites will migrate to the new versions as CAD functions (e.g., spline fit) are validated and as their budgets and priorities allow. It is possible that a superior product from another CAD supplier will supercede Pro/Engineer™ sometime in the future. Our short-term tactics then is to press for consensus use. NNSA's long term strategy, with support from NWC sites, is to pursue a standards approach by participating in the international *Standard for the Exchange of Product Model Data (STEP)*, and through development of NWC Technical and Infrastructure Business Practices for MBE/M.

We are also sensitive to the fact that 3D solid models of weapon components and assemblies represent unprecedented high-density classified RD information. We are relying on continued support and development of SecureNet infrastructure across the NWC. We also need development of *Need-To-Know* systems and practices for controlled access to weapons models, and deployment at each of the NWC sites as soon as possible.

Recommendations

The Plants and Laboratories have been preparing for model-based practices and investing in MBE/M systems for over 10 years. We will probably never be more prepared for the transition to MBE/M systems and practice for weapon production than we are right now: most designs are being done on common vendor software; our initial cross-site experiences have been encouraging; and, the ADAPT and Readiness Campaigns are prepared to provide the leadership, direction, and focus resources on problems as they arise.

We need every advantage possible from our investments to successfully meet the challenges of aggressive LEP schedules with limited budgets, and without compromise to quality of the weapons we put back in the stockpile. Now, more than ever before, we rely on our investments in new systems rather than old established practices to meet our programmatic needs of high quality with reduced schedules and costs. We look to LEP program managers at NWC sites to commit to model-based methods by supporting deployment and use of MBE/M systems to meet their program needs.